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Abstract

This study focuses on the amosite mining region in South Africa and associated health effects, compared to other mined asbestos fiber types. Historically, dust and fiber levels were high in the amosite mills and mines, and many miners and members of the surrounding communities were exposed to the fibers. Research has shown that amosite produces both benign and malignant disease. Nevertheless, the mesotheliomagenic potential of amosite is several fold lower than crocidolite. The risk of disease associated with amosite exposure is difficult to quantify. Reasons for this include the scarcity of available information, including fiber measurements, and case ascertainment, as well as the juxtaposition of the amosite and crocidolite asbestos seams in South Africa.

Keywords: Amosite; Mesothelioma; Crocidolite; South Africa; Asbestos

1. Introduction

South Africa is unique in that all three commercially important types of asbestos occur and have been mined and widely exported from this country. South Africa was the world's main commercial source of amosite (grunerite), the name of which is derived from "*a*sbestos *m*ines *o*f *S*outh Africa".

South Africa was at the forefront of the asbestos mining industry. However, there is a lack of research and documentation monitoring asbestos mines and mills. What little information that is in the public domain needs to be interpreted with knowledge of the background to geography, geology and demographics. The Pneumoconiosis Research Unit (PRU), now the National Institute for Occupational Health (NIOH), in Johannesburg participated in many of the published studies, and also carried out some unpublished work. This information has been drawn on for interpretation of the available literature.

Historically, there were two amphibole asbestos mining areas in South Africa. Cape Crocidolite was mined in the Northern Cape Province asbestos field, which extends for a length of about 540kms (Fig. 1). No amosite was mined in this area. Five hundred kilometers away, in the north eastern part of the country, is the Pietersburg asbestos field (in Limpopo Province), where both Transvaal crocidolite and amosite were mined. This field is around 100 kilometers long and lies along the Olifants River and its tributaries (Webster, 1973). There was very little movement of population between these regions, although more senior mine officials were sometimes transferred between the different mines and mining regions.

Many small mines and mills operated in the Pietersburg asbestos field, from about 1920, producing Transvaal crocidolite and amosite from deposits in which seams of the two amphiboles often overlapped. Crocidolite mining here (which was in the form of addits) however, never reached the production levels of those in the Northern Cape. The deposits were small and scattered, and were considered to be of poorer grade than those in the Northern Cape.

The largest and most important mine in the Pietersburg asbestos field was the Penge group of mines (comprising Penge, Weltevrede and Kromellemboog mines) on the south-eastern extremity, where only amosite was mined (Coetzee, 1976). Penge was the only mine in the region that had deep mine shafts. Amosite production began in 1914 at Penge and continued for more than 70 years, until 1992 (Felix, 1997). This became the largest mine in the area and, from about 1976 until it closed, the world's only commercial source of amosite. Production peaked at 100,000 tons in 1970 (Fig. 2) when 7,000 workers were employed; at this time around 13,000 workers were employed in the Northern Cape (crocidolite) asbestos field (Rees, 1999). Some of the reasons for the popularity of amosite were the extent of the ore body and the relative ease with which the deposits could be mined. Amosite production exceeded that of Cape crocidolite until the early 1960s (Fig. 2).

In the early 1960s Europe and North America were the major importers of South African asbestos. The picture had changed radically by the late 1980s. At this stage, the Far East was importing 90% of the chrysotile stocks, 70% of amosite and 40% of crocidolite (Harington and McGlashan, 1998). In 1988 the Japanese government regulated against the use of amosite and, by 1991, amosite had been phased out completely. The collapse of this Far East market led to the closure of the Penge mine in June 1992.

Almost all the smaller operations had closed by 1976. However, chrome, platinum, andalusite, vanadium and iron continue to be mined in the region.

2. Exposure

> "It is difficult to recover the exposure story of South Africa's asbestos mines. The official record is incomplete, and the accounts from the mining companies, and to a lesser extent from the Department of Mines, are not always reliable. Often they give a distorted picture of dust levels" (McCulloch, 2002).

In 1949, Schepers visited Penge mine as part of the first official government radiological and clinical survey of the Pietersburg asbestos field. He encountered deplorable working conditions:

> "Exposures were crude and unchecked. I found young children, completely included within large shipping bags, trampling down fluffy amosite asbestos, which all day long came cascading down over their heads. They were kept stepping lively by a burly supervisor with a hefty whip. I believe these children to have had the ultimate of asbestos exposure" (Schepers, 1965).

2.1. Fiber measurements

Despite the fact that measurements were few and far between, historical scientific evidence (sparse as it was), plus anecdotal evidence, clearly indicate~~s~~ that the levels of asbestos fibers in and around the Penge mining area were exceptionally high.

What measurements were made had their own inherent problems; they were often averaged for the mine and the mill, and then for groups of mines, or over time. At varying times measurements were made using Konimeters or thermal precipitators, and strategic and personal samplers. It was, furthermore, not always clear what was being measured, viz. particles and / or fibers. The definition of a fiber is determined by the ratio of its length to diameter and the measurement of the diameter itself. This definition was not constant; the fiber length: diameter ratio was changed from two to three in 1965, and the diameter from five to three microns in 1970 (du Toit, 1984).

In 1947, measurements in the Penge mills ranged from 162 to 720 p/ml, and underground, from 80 to 228 p/ml (Sluis-Cremer, 1965) (Table 1). Levels appeared to increase in the 1950s, probably due to mechanization, when 30% of the counts in the mills were above780 p/ml (Sluis-Cremer, 1965). Rendall, using personal samplers, recorded counts of up to 327 f/ml in the mills and more than 100 f/ml in a range of other surface jobs (Rendall, 1971); underground levels were < 5 f/ml. In the 1980s the fiber counts at Penge ranged from 0.1 to 6.5 f/ml in the mills, and from 0.2 to 1.0 f/ml underground (Dept. Minerals and Energy, personal communication).

2.2. The amosite work force / occupational exposure to amosite

Penge was a purpose-built town which developed only as a consequence of the mining activity. There was a high labor turnover, perhaps because of the lack of a stable, entrenched community, at times close to 100% per annum (McCulloch, 2002). Many of the workers came from neighboring countries, returning home when they became ill or when they left their jobs for other reasons.

There were very few white miners in the area, and most of them worked at Penge. The black miners were more dispersed within the Pietersburg asbestos field, and thus may have been exposed to both amphiboles. This may have been one of the reasons why some of the studies were limited to the white ethnic group. However, they comprised a small proportion of the Penge work force: in 1963 Penge had 360 white and 6,500 black workers (McCulloch, 2002).

There were many small mills in the Penge area, in addition to two mills at Penge mine. They were of basic design and caused extensive environmental pollution in the valleys (McCulloch, 2002). The workers themselves were exposed to extremely high fiber levels, as sweepers, sorters and packers.

Cobbing, whereby the fiber was loosened from the rock, was done primarily by women and children at Penge, as well as at the smaller operations. In 1940, 25% of the Penge workforce were boys younger than 16 (McCulloch, 2002). The employment of children younger than 16 years of age was only prohibited in 1973. Even when a new second mill was built at Penge in the mid-60s, extensive hand cobbing continued because the ‘new mill’ broke down often, primarily because they continued to process large quantities of iron stone.

2.3. Environmental exposure to amosite

Fiber exposure was not confined to the immediate vicinity of the mines and mills. Van Sittert and Rendall (1988), demonstrated during the operation of the Penge mill, that fibers were detectable at a distance of up to 100 kms from Penge.

There was also contamination from water. There was, and still is, no piped water in the rural areas where black people are living. Tailings, deliberately put into the rivers and streams, washed down to the Penge area. In the dry season, the rivers dried up, leaving fibers on the banks. These were then blown about by the strong prevailing winds. Water-borne fiber exposure was compounded when the rivers were used for domestic use such as drinking, bathing and laundry. Children were especially vulnerable as they often played on tailings dumps or on playgrounds covered with asbestos fibers. Asbestos was also used by the community for, amongst other things, brick making and decorating houses (Felix, 1997).

In 1988, some 12 years after the closure of the last addits in the region, personal and strategic sampling was performed in the Mafefe district, which is in very close proximity to the site of Penge mine (Felix, 1997). Children were exposed to the highest concentrations (mean 0.02 f/ml; range 0.002- 0.090 f/ml).

2.4. Size of exposed population in Pietersburg asbestos field

In 1965 the number of persons employed at Penge was around 10,000, similar to the Northern Cape asbestos field (Sluis-Cremer, 1965). The estimates for miners in 1970 were around 13,000 in the Northern Cape and 7,000 at Penge (Rees, 1999). The numbers employed in the chrysotile mines were always fewer; in 1970, there were 1,200 employees. One can only estimate the sizes of the populations at risk of environmental exposure. The Northern Cape comprised a larger geographical area, but the population density was higher in the Pietersburg asbestos field. In Felix's thesis (1997), she identified 64% of 611 randomly selected adults in the Mafefe district of the Pietersburg asbestos field with a history of environmental asbestos exposure.

3. Health effects of amosite exposure in South Africa

Studies of asbestos-related diseases in South Africa began with the work on chrysotile miners (Slade, 1931). This work was not continued into the 1940s, however, perhaps as a consequence of World War II. Webster revived the issue of asbestos and health in the 1950s, contributing significantly to the discovery of the link between exposure to crocidolite and the development of mesothelioma (Webster, 1954). Following the publications of Wagner in the 1960s (Wagner et al., 1960), research activity focused on crocidolite in the Northern Cape Province. Despite intensive mining of amosite in South Africa for more than 70 years, relatively little research has been done in the country on the health effects of exposure to this fiber type. One reason could be the juxtaposition of the seams of amosite and crocidolite in the Pietersburg asbestos field. Crocidolite was mined in close proximity to Penge mine. Thus it was, and still is, very difficult to identify, with absolute certainty, individuals who were exposed to only amosite.

3.1. Non-malignant amosite-associated disease

The research that has been done on amosite-exposed workers has identified high rates of both pleural abnormalities and parenchymal lung disease (Table 2). Because of the paucity of occupational hygiene data, and also because the mines seldom maintained comprehensive employment records, particularly for black workers, these studies generally did not have data to enable dose-response analyses.

The first research into asbestos-related disease at Penge was conducted in the 1960s by the Pneumoconiosis Research Unit (PRU), and published in 1965 (Sluis-Cremer, 1965). An autopsy series of black miners who died while employed identified asbestosis (although often of slight degree) in 80% of the Penge miners and 72% of the Cape crocidolite miners (Table 2). The mean age and service of both groups was the same, viz. 43 years and four years, respectively. A field survey of 2,389 persons, identified cases of asbestos-related disease (this included both pleural abnormalities and parenchymal disease) in the Northern

Cape crocidolite and Penge amosite mining regions. Sluis-Cremer (1965) found higher proportions of fibers / asbestos bodies (these terms were used interchangeably) in sputum in the Northern Cape population than in the Penge community. Likewise, the prevalence of asbestos related disease was higher in those exposed to Cape crocidolite. This held true for both occupational and environmental exposures.

Irwig et al. investigated Cape crocidolite and amosite currently employed miners for benign pleural disease and asbestosis. They found a significantly higher prevalence of pleural abnormalities in the amosite exposed workers with more than 15 years of service, compared to the crocidolite miners (34% vs 17%). They detected no such difference for parenchymal disease (Irwig et al., 1979).

In a community-based study of a population exposed to asbestos dust in an area heavily contaminated by dust from mining, milling and uncontrolled tailings dumps, pleural changes were found in 52% of occupationally exposed subjects and in 34% of subjects with only environmental exposure (Felix, 1997).

Davies et al. (2001) studied the prevalence of asbestos disease in 770 women who had worked on asbestos mines in the Pietersburg asbestos field from 1929 to 1980; 80% were cobbers. A diagnosis of pleural and/or parenchymal asbestosis was made in 96% of cases. He ascribed the high prevalence to exposure to high levels of amphibole asbestos dust, predominantly amosite, and to the long residence time of dust in the lungs (Davies et al., 2001).

3.2. Mesothelioma

The occurrence of mesothelioma in the Pietersburg asbestos field has led to some controversy. In the 1960s, an orthodoxy developed amongst establishment scientists in South Africa that mesotheliomas did not result from exposure to amosite. This was articulated most strongly at the 1965 New York Academy of Sciences conference in papers by Sluis-Cremer (1965) and Webster (1965). Sluis-Cremer (1965) suggested real differences in the carcinogenicity of the mesothelium between amosite and crocidolite fibers.

Several factors contributed to the development of this view. The available evidence indicated a high prevalence of mesotheliomas in the Northern Cape crocidolite asbestos field (Wagner, 1960). However, there were no reports of mesothelioma from the Pietersburg asbestos field, although there was a high prevalence of benign asbestos disease (Sluis-Cremer, 1965).

Nevertheless, this view was soon challenged. The Asbestos Tumour Reference Panel was set up in 1965 at the PRU, to which all cases of mesothelioma were to be sent for expert review of the disease and confirmation of diagnosis. It was presumed that all cases of mesothelioma in South Africa were being reported to the registry. Of the first 375 subjects, only 4 (1%) had worked at amosite mines; but they had also been exposed to crocidolite elsewhere (Webster, 1973).

Since then, the evidence for low rates of mesothelioma in amosite asbestos exposed workers has been corroborated by a number of researchers. In 1992, Sluis-Cremer and colleagues published a study which examined mortality in three cohorts of amphibole miners. The cohorts were established in 1980, using employment records of white men who were employed from 1945 to 1955. There were 3 212 amosite miners, 3,430 Cape crocidolite miners and 675 men with exposure to both amphiboles. A total of 30 mesotheliomas were identified. Four of these cases had been exposed to pure amosite, six to both amosite and Cape crocidolite, and 20 to Cape crocidolite only.

The calculated incidence of mesothelioma, per 100,000 person-years, for exposure to Cape crocidolite was almost 6 times that for amosite (44.6 and 7.8 respectively). Likewise, the PMR for crocidolite exposure was much higher than that for amosite (almost eight times; PMR 4.7 vs 0.6). Sluis-Cremer et al. (1992) stated that, while amosite can cause mesotheliomas "there can now be no question that crocidolite is far more dangerous than amosite at least in so far as mesothelioma is concerned". There is no evidence, from South Africa, to the contrary. This gradient of mesotheliomagenic risk by fiber type is supported by other studies (Hodgson and Darnton, 2000).

Rees reported on a case control study undertaken in the period 1988 to 1990 (Rees et al., 1999). One hundred and twenty three mesotheliomas were identified. Again, crocidolite exposure was mostly implicated in the development of mesothelioma. Three cases mined amosite and three mined both amosite and crocidolite. Of the 22 environmental mesotheliomas, 20 (91%) had exposure to Cape crocidolite, and two to both amosite and crocidolite. There were no cases associated with chrysotile exposure.

Recent pathology records from the Limpopo Province, where the Pietersburg asbestos field is located, suggest that there may be mesotheliomas that have not been included in published studies. In the 15 months from February 1989 to April 1990, 16 mesotheliomas were diagnosed at the Pietersburg branch of the South African Institute of Medical Research (Felix, 1997).

Over the last few years only one of 50 cases that have come to autopsy at the NIOH had amosite exposure recorded.

3.3. Lung cancer

Sluis-Cremer et al. (1992) calculated the SMR due to lung cancer for crocidolite exposure to be higher than that for amosite exposure (2.03 versus 1.38; relative toxicity 1.85). This difference, however, was much less than that for mesothelioma. Cancer registration studies have reported no excess of lung cancer for amosite exposed workers (Higginson and Oettle, 1960; Botha, et al., 1986). However, lung cancer studies in asbestos workers are confounded by smoking. Only Sluis-Cremer et al.'s 1992 study controlled for smoking.

4. Discussion and conclusions

The South African asbestos industry was large, profitable and an important source of foreign earnings (95% of production was exported). However, little was put back in terms of research, occupational hygiene and health surveillance. Currently, at the NIOH, where the lungs of deceased mineworkers are examined, asbestos-related diseases continue to be seen; this will continue for some decades, despite the closure of asbestos mines.

There is solid evidence of high rates of benign asbestos disease from amosite. There is no question that amosite causes mesothelioma (and lung cancer).

The burden of mesothelioma in the Pietersburg asbestos field is uncertain, but is almost certainly lower than in the Northern Cape Province, even taking into consideration problems with under ascertainment. There is no study of crocidolite miners from this area not also exposed to amosite. Nevertheless, ooccupationally associated cases from the Pietersburg asbestos field have been infrequently documented, and, in contrast to Cape crocidolite, there are no environmental mesotheliomas attributable solely to amosite exposure.

Cumulative amosite and Cape crocidolite production levels were similar for the asbestos mining period (Harington and McGlahan, 1998). The numbers of people exposed (workers and residents), were also comparable. Amosite was mined from the turn of the last century until 1992; the exposure periods are thus also comparable.

The juxtaposition of the seams of amosite and crocidolite in the Pietersburg asbestos field make it very difficult to identify, with absolute certainty, individuals who were exposed to only amosite. Nevertheless, the available evidence from South Africa supports the concept of a fiber gradient in mesotheliomagenic potential for South African asbestos. Those exposed to crocidolite exposure appear to have the highest risk for developing mesothelioma, followed by amosite; chrysotile has not been implicated in the development of this malignancy in South Africa. One explanation for this may be relative lack of contaminating tremolite, an amphibole that variably occurs with chrysotile ores (Rees et al., 2001).

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Figure 1: Map of asbestos mining areas in South Africa. Wagner et al. (1960) reports a cluster of mesotheliomas associated with the Northern Cape asbestos fields west of Kimberley.

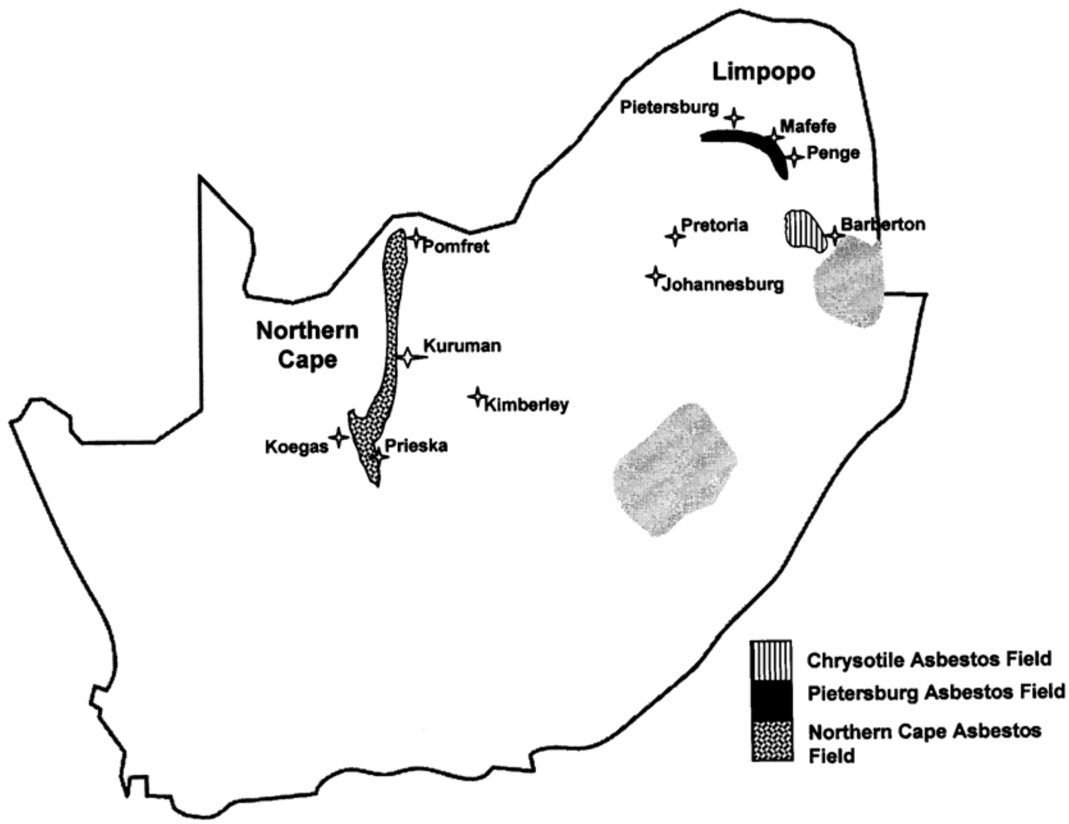

Figure 2: Asbestos production in South Africa, 1940 to 1980

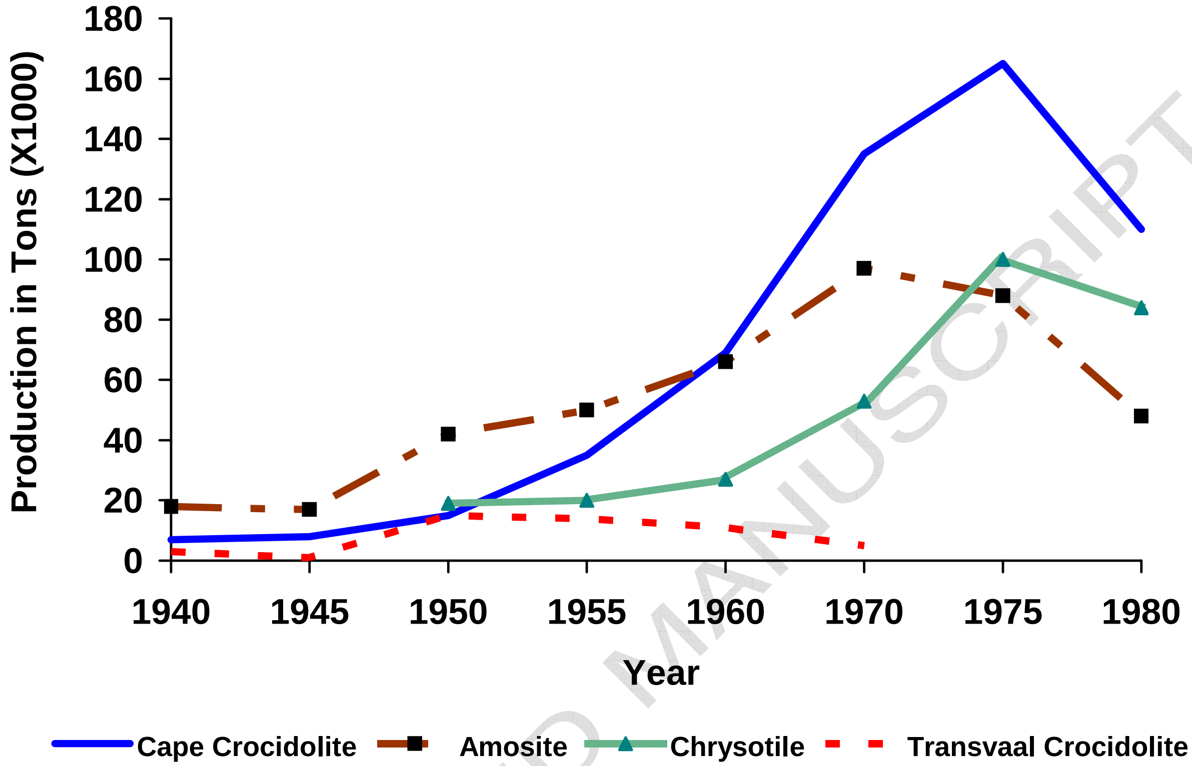

Table 1: Fiber measurements at Penge

Source	Year	Site	Particles/cc	Fibres/ml
Sluis-Cremer et al. 1992	1945	Surface		150
		Underground		14
Sluis-Cremer 1965	1947	Mills	162 – 720	
		Underground	80 – 228	
	1951	Mills	30% >780	
Sluis-Cremer et al. 1992	1960	Surface		56
		Underground		6
Sluis-Cremer et al. 1992	1970	Surface		40
		Underground		4
Rendall 1971	1970	Mills		1.4 – 326.7
		Other surface jobs		0.2 – 113.4
		Underground		< 5
Dept. Minerals and Energy, personal communication	1986	Mills		0.1 – 6.5
		Underground		0.2 – 1.0

Table 2: Studies on benign disease in amosite-exposed persons in South Africa

Author	Study design	Study population	Study period	Findings
Sluis-Cremer (1965)	Autopsy series (histology)	Current miners: *PAF: 64 **CCF: 87	1959 - 1964	Asbestosis[1] 80% 72%
	Field survey (radiology)	2389 persons *PAF Occ *PAF Env **CCF Occ **CCF Env	1960 - 1962	Sputum fibres °ARD[2] 39% 16% 23% 2% 42% 22% 28% 5%
Irwig (1979)	Prevalence (radiology)	Workers: *PAF: 548 **CCF: 882 *PAF: 548 **CCF: 882	1970 - 1975	Pleural Abnormalities[3] 34% 17% Asbestosis[4] 23% 27%
Felix (1997)	Community-based (radiology)	Men & women residents of Mafefe	1988	Pleural Abnormalities[5] Env: 34% Occ: 52%
Davies (2001)	Prevalence (radiology)	770 Females Ex-cobbers	1990s	Pleural Abnormalities plus asbestosis[6] 96%

*PAF = Pietersburg Asbestos Field (Amosite/ Penge)
**CCF = Cape Crocidolite Field
°ARD = asbestos-related disease

1 parenchymal linear, reticular or nodular disease
2 parenchymal linear, reticular or nodular disease; or calcified pleural plaques
3 pleural thickening, pleural calcification or obliteration of the costophrenic angle (ILO definition)
4 irregular opacities with profusion > 1/0 (ILO definition)
5 pleural plaques, calcified pleural plaques, pleural thickening, obliterated costophrenic angle
6 pleural plaques, calcified pleural plaques, pleural thickening; and parenchymal linear, reticular or nodular disease